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The preview benefit: Visual marking, feature-based inhibition, temporal segregation, or onset capture?

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The preview effect demonstrates that if observers in a visual search task are allowed a preview of a subset of elements before another subset of elements is added to the display, the first subset of elements no longer competes for attentional selection in the search process. Watson and Humphreys (1997) explained this effect by proposing that the locations of previewed elements are top down inhibited during the preview by a process they refer to as visual marking. The results of recent studies cannot easily be explained by the original visual marking account. As a consequence, three alternative views have emerged. According to one notion, a feature-based inhibition account, the preview benefit is mediated by inhibition applied at the level of feature maps in addition to location-based inhibition. A second view, the temporal segregation hypothesis, assumes that prioritized selection of new elements results from observers being able to selectively attend to one group of elements that can be perceptually segregated from another group on the basis of temporal asynchrony. A third view assumes that the preview benefit is caused by onset capture mediated by the appearance of the new elements. The present paper reviews the key findings concerning the preview benefit with the aim to resolve some of the controversies about how observers prioritize selection of new over old elements.

We live in a continuously changing visual world offering an almost infinite number of stimuli to process. Yet, the human information processing capacity is limited. To behave efficiently, visual selection is required to distinguish relevant from irrelevant stimuli. One way in which people select visual information is through the prioritization of new over old information. That is, people tend to attend to new objects at the expense of objects already present in the visual field (e.g., Donk & Theeuwes, 2001; Jonides & Yantis,

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1988; Kahneman, Treisman, & Burkell, 1983; Theeuwes, 1991, 1994; Watson & Humphreys, 1997; Yantis & Hillstrom, 1994; Yantis & Johnson, 1990; Yantis & Jones, 1991; Yantis & Jonides, 1984, 1990). The present paper aims to provide an overview of the research concerning the mechanisms underlying prioritized selection of multiple new objects.

Scientific evidence for prioritized selection of new over old objects was initially provided by Kahneman et al. (1983), who demonstrated a reduced distractor interference effect when distractors were displayed prior to the appearance of the imperative stimulus. More recently, Watson and Humphreys (1997) also demonstrated that previewing a set of elements reduces their effect on reaction time (RT). In this study, observers were presented with one set of elements (old elements) for at least 400 ms before another set of elements (new elements) was added to the display. The task of observers was to indicate the presence or absence of a prespecified target element that could only appear among the new elements. Search performance in this preview condition was compared to that in a condition in which all elements were presented simultaneously and a condition in which only the new elements were presented. The results of Watson and Humphreys demonstrated a preview benefit, i.e., a higher search efficiency in the preview condition than in the condition in which all elements were simultaneously presented. In fact, observers were able to selectively ignore the old elements so that search efficiency in the preview condition was equal to that in the condition in which only the new elements were presented. The results indicated that observers were able to selectively assign priority to the new over old elements. To explain the results, Watson and Humphreys proposed that observers are able to selectively inhibit the locations of the old elements in anticipation of the new elements, a process they referred to as visual marking. Visual marking presumably occurs in a top-down fashion: Observers are assumed to inhibit the locations of the old elements during the preview only if it is advantageous for them to do so. The top-down goal-based inhibition of the locations of the old elements biases selection towards the new elements upon their appearance (see also Humphreys, Jung-Stalmann, & Olivers, 2004; Kunar, Humphreys, Smith, & Watson, 2003c; Watson & Humphreys, 1997, 2000).

Even though visual marking can account for much of the data obtained with the preview paradigm, the results of many recent studies cannot be easily explained by it (e.g., Donk & Theeuwes, 2001; Jiang, Chun, & Marks, 2002b; Watson & Humphreys, 1998). This development led to a differentiation along three theoretical lines.

First, various authors adhere to the basic idea that observers use a top-down inhibitory mechanism to prevent old elements from being processed. However, in contrast to the initial visual marking account, nowadays many authors assume that the inhibition may also be applied at the level of whole

feature maps (Braithwaite & Humphreys, 2003; Braithwaite, Humphreys, & Hodsoll, 2003; Kunar, Humphreys, & Smith, 2003a; Olivers & Humphreys, 2002, 2003; Olivers, Watson, & Humphreys, 1999; Watson & Humphreys, 1998). This view will be referred to in terms of a feature-based inhibition account to discriminate it from the original visual marking account.

Second, it has been proposed that prioritized selection is based on the presence of temporal segregation cues (Jiang et al., 2002b). According to this view, new elements are prioritized over old ones because new and old elements can be segregated into two perceptual groups due to their temporal asynchrony. Subsequently, attention can selectively enhance the processing of one group over the other. Even though this temporal segregation account of prioritized selection was put forward as an alternative to the visual marking account, it bears some resemblance to this theory. Most importantly, according to the temporal segregation hypothesis, prioritized selection is assumed to be based on a top-down process.

Finally, others have completely refuted the idea that observers prioritize new over old elements by top-down processing. Instead, it is assumed that prioritizing new elements occurs because the luminance onsets accompanying the appearance of the new elements automatically attract attention in a bottom-up fashion (Belopolsky, Theeuwes, & Kramer, 2005; Donk & Theeuwes, 2001, 2003; Donk & Verburg, 2004). This view will be referred to as the onset account. Because the preview benefit is assumed to be caused by a bottom-up process, the onset account contrasts strongly with the other accounts of the preview benefit.

The present paper reviews the key findings on the preview benefit with the aim to resolve some of the controversies about how observers prioritize selection of new over old elements. The first section presents results from recent experiments using the preview paradigm as it was originally introduced by Watson and Humphreys (1997). The results of these recent studies tend to favour a feature-based inhibition account over the original visual marking account. Neither a temporal segregation account nor an onset account can appropriately explain the results presented in this section. The second section describes findings that cannot be explained on the basis of visual marking and feature-based inhibition. The results presented in this section primarily support the onset account. The final section aims to reconcile the alternative theoretical accounts and provides concluding remarks.

THE RELEVANCE OF FEATURE DIFFERENCES IN PREVIEW SEARCH

Since Watson and Humphreys (1997) introduced the idea of visual marking, a number of authors have been involved with the question how old elements

are inhibited or, as expressed by Kunar, Humphreys, Smith, & Hulleman (2003b) in their title, "What is 'marked' in visual marking?" (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003; Kunar et al., 2003a; Olivers & Humphreys, 2002, 2003; Olivers et al., 1999; Watson & Humphreys, 1998).

Initially, Watson and Humphreys (1997) proposed that observers actively inhibit the locations of old elements to prevent them from being processed. In their Experiment 7, observers searched for a blue letter "H" among green "H"s and blue "A"s. The preview display consisted of one, four, or seven green "H"s followed after 1000 ms by the addition of seven, four, or one green "H"s, respectively, along with eight blue items. The results demonstrated that varying the proportion of old to new green distractors substantially affected search efficiency. According to Watson and Humphreys, this suggests that inhibition of the old green distractors was location based and not feature based, as in the latter case the proportion of old to new green distractors should not have mattered. However, Experiment 7 did not allow a comparison between the effects of the number of new green and new blue elements. As a consequence, it is unclear whether there really was no colour-based inhibition at all.

Evidence for the idea that prioritization of new elements can also be based on inhibition applied at the level of whole feature maps, stems from a later study. In six experiments, Watson and Humphreys (1998) showed that observers can prioritize new elements even when old elements are moving. To account for this finding, they proposed that observers may use one of two different ways to inhibit the processing of old elements. They argued that with static old elements, inhibition is location based, whereas with dynamic old elements, inhibition is feature based. That is, to prevent old moving elements from being processed, inhibition is assumed to be applied to a common property of those elements such as their colour.

Since Watson and Humphreys (1998), the feature-based inhibition hypothesis gained much credit, not only to account for results obtained with moving displays but also with static displays (see also Olivers, Humphreys, and Braithwaite, 2006 this issue). For example, Olivers and Humphreys (2002) performed an experiment (Experiment 4) in which observers had to localize a blue "H" target among previewed green "H"s and new blue "A"s. After the preview task, an additional search display was presented consisting of green "A"s and one green "H" target that also had to be localized. The results showed that if search for the blue "H" target in the preview task was inefficient (as induced by an attentional blink), search for the green "H" target in the second search task was efficient. If preview search was efficient, search performance in the second search task was less efficient. Olivers and Humphreys (2002) concluded that the preview benefit is at least partly due to feature-based inhibition. On the one hand, failures to successful inhibit the colour of the old elements lead to relative good

performance in a subsequent search task in which the target shares the colour with the previously previewed elements. On the other hand, if observers are successful in inhibiting the previewed elements, subsequent search for a target sharing its colour with the previewed elements is hampered due to nonspatial inhibition of the colour of the previewed elements.

Braithwaite et al. (2003) also provided evidence for inhibitory carryover effects in preview search based on colour (see also Braithwaite & Humphreys, 2003). In a sequence of five experiments, Braithwaite et al. demonstrated that colour similarity between old and new elements has a profound effect on search efficiency in a preview task. For instance, when the target in the search display shared its colour with the majority of the previewed elements, search efficiency was seriously hampered in comparison to when this was not the case. Braithwaite et al. attributed this effect to feature-based inhibition. That is, colour-based inhibition of the old elements was assumed to be carried over to the target if it had the same colour.[1]

Finally, Olivers and Humphreys (2003) combined the preview paradigm with the presence of a feature singleton in the search display. For example in Experiment 2, observers had a preview task in which they had to search for a target among previewed old elements and new elements. Among the new elements, a singleton could be presented which was always unique in a simple feature dimension relative to the new elements. The singleton presented could share one or more features with the previewed old elements. Olivers and Humphreys reasoned that if the previewed old elements are inhibited and if this inhibition is feature based, the extent to which the singleton captures attention should be modulated as a function of its similarity to the previewed elements. The results demonstrated that if a singleton was similar to the previewed elements, the effects of singleton presence were less than if the singleton was dissimilar to the previewed old elements. These results again provide evidence for the idea that the preview benefit is caused by feature-based inhibition.

In sum, recent studies have provided cumulative evidence for feature-based inhibition as an explanation for the preview benefit. Whereas initially, feature-based inhibition was discarded as a viable explanation for the preview benefit (in Watson & Humphreys, 1997), increasingly more studies are demonstrating that feature-based inhibition does play a role in the preview paradigm. The role of feature-based inhibition in the preview benefit has gained much credit not only to account for findings with moving stimuli (Watson & Humphreys, 1998), but also to explain results obtained with

[1] In addition to colour-based inhibition, Braithwaite et al. (2003) as well as Braithwaite and Humphreys (2003) also assume that the prioritization of new elements can be further supported by the possibility to use an anticipatory set for a known target colour.

static displays (Braithwaite & Humphreys, 2003; Braithwaite et al., 2003; Kunar et al., 2003a; Olivers & Humphreys, 2002, 2003; Olivers et al., 1999).

At this point, it is important to note that in the preview paradigm used in the above studies, old elements were always different from new elements in a simple feature-dimension. Theeuwes, Kramer, and Atchley (1998) were the first to point this out. They argued that the original findings of Watson and Humphreys (1997) might not be unique to preview search but instead represent another demonstration of subset selective search by colour (e.g., Egeth, Virzi, & Garbart, 1984; Kaptein, Theeuwes, & van der Heijden, 1995). To investigate this issue, Theeuwes et al. had observers search for a white "H" among a variable number of old and new other white letters. Numbers of old and new letters were independently manipulated permitting a direct comparison between the effect of the number of old elements and the effect of the number of new elements on search performance. The results showed that even though there was no colour difference between old and new elements, observers were perfectly able to prioritize the selection of new over old elements as evident from the finding that only the number of new elements affected search performance whereas the number of old elements did not. Theeuwes et al. concluded that prioritized selection of new over old elements was not just another demonstration of subset selective search by colour.

Even though the results of Theeuwes et al. (1998) are in line with the original visual marking account of Watson and Humphreys (1987), they cannot be explained by a feature-based inhibition account. In fact, old and new elements were indistinguishable from each other except for the moment in time at which they were presented. When old and new elements share all their features, observers cannot use a mechanism of feature-based inhibition to prioritize selection of one over another subset of elements. The next section will be concerned with research in which old and new elements only differ in their temporal onset.

INHIBITION, TEMPORAL SEGREGATION, OR ONSET CAPTURE?

As noted in the previous section, the results of studies in which the old elements carried a different colour than the new elements are in line with the idea that the preview benefit is caused by feature-based inhibition. However, studies in which old and new elements cannot be discriminated on the basis of a simple feature have generally led to completely different views on how observers prioritize selection of new over old elements (but see Theeuwes et al., 1998).

For example, Jiang et al. (2002b) had observers search for a rotated "T" among rotated L-shaped objects. Old and new elements could not be distinguished from each other on the basis of one simple feature. The results showed that the preview benefit disappeared if the old elements changed shape or luminance at the onset of the new elements, whereas preview search was not disrupted when the old elements changed shape and luminance prior to the presentation of the new elements. Moreover, preview search was also unaffected when the background changed. According to both a visual marking account and a feature-based inhibition account the preview benefit should have been disrupted by asynchronous as well as synchronous changes in the old elements. Watson and Humphreys (1997) postulated that any dynamic change should be disruptive for the preview benefit because dynamic changes are assumed to reset the inhibition process. In contrast, according to a temporal segregation account, the temporal asynchrony is critical in determining whether or not a preview benefit occurs. The results therefore provided evidence favouring the temporal segregation account and against the inhibition accounts.

Quite different were the conclusions of Donk and Theeuwes (2001). They had observers search for a green target letter "H" among a variable number of green old and new letters on a grey background. The numbers of old and new elements were independently manipulated (see also Jiang, Chun, & Marks, 2002a; Theeuwes et al., 1998). Old and new elements could not be distinguished from each other on the basis of a simple feature. The presentations of the old and new elements were or were not accompanied by a luminance change. The results showed that prioritizing selection of new elements was critically dependent on whether or not the appearance of new elements was accompanied by an abrupt luminance onset. Search performance was only independent of the number of old elements if new elements were presented with abrupt luminance onsets. If there was no luminance onset of new elements, search performance depended on both the number of new elements and the number of old elements. The results did not depend on the onset characteristics of the old elements. In other words, for a preview benefit to occur, new elements were required to appear with luminance onset irrespective of the onset characteristics of the old elements. These results cannot easily be explained by the original visual marking account, nor by the feature-based inhibition notion. In fact, to explain the results of Donk and Theeuwes a visual marking account should include the idea that luminance onsets are crucial for prioritized selection. One might, for example, argue that the effect of inhibiting the locations of the old elements is to enable new onsets to enhance activation in an attentional system responsive to dynamic change in the visual environment. If the new elements do not activate this system (i.e., when they are equiluminant with the background) then effective prioritization should not occur. A feature-based inhibition account cannot

explain the results of Donk and Theeuwes, since there were no feature differences between old and new elements. Because there were no variations in the temporal properties of the stimuli over conditions, a temporal segregation account (Jiang et al., 2002b) can neither explain the results. If one assumes that other forms of perceptual grouping play a role in the preview benefit, one would have expected that it should have been relatively easy to segregate two groups of elements if they had different onset characteristics, i.e., when the old elements appeared with onset whereas the new elements did not. The results of Donk and Theeuwes showed that this is not the case. To explain their results, Donk and Theeuwes (see also Donk & Theeuwes, 2003; Donk & Verburg, 2004) proposed that prioritized selection is caused by luminance onset capture (e.g., Theeuwes, 1991; Yantis & Johnson, 1990; Yantis & Jones, 1991; Yantis & Jonides, 1984, 1990). According to this onset account, new elements are assumed to be automatically prioritized over old elements because the abrupt luminance onsets accompanying the appearance of the new elements generate a large bottom-up activation biasing observers to prioritize the processing of new elements over old ones. Although Donk and Theeuwes' original study did not allow one to conclude that prioritized selection is based on a bottom-up process, the results of a more recent study (Donk & Theeuwes, 2003) suggest that this is indeed the case.

In Donk and Theeuwes (2003), observers were presented with displays containing one set of elements consisting of green "H"s and blue "A"s (old elements) followed after a certain time interval by a second set of elements also consisting of green "H"s and blue "A"s (new elements). Observers were instructed to search for the presence of a blue "H" target, which was presented on 50% of the trials with equal probability among the old and new elements (Experiments 1 and 2) or twice as often among the old elements than among the new elements (Experiment 3). If the target was presented among the old elements, upon presentation of the new elements, one of the previously presented green "H"s turned blue. The colour change from green to blue was not accompanied by a luminance change, i.e., the colours green and blue were equiluminant to each other. If the target was presented among the new elements, one of the new elements was the blue "H" target. The results showed that if the target was presented among the new elements, search performance only depended on the number of new elements, whereas if the target was presented among the old elements, search depended on both the number of old and the number of new elements. These results demonstrated that new elements were prioritized for selection over old ones even though observers had no incentive to do so. These results provide strong evidence against any notion assuming that prioritized selection of new over old elements is based on a top-down process. According to both a visual marking account and a feature-based inhibition account, prioritized

selection is contingent on the maintenance of an appropriate goal state. The temporal segregation hypothesis also assumes prioritized selection to be goal driven. In fact, according to Jiang et al. (2002b), an observer may allocate attention to whatever group of elements (i.e., the old or the new elements) is known to contain the target.[2] The results of Donk and Theeuwes (2003) showed that this is not the case. Observers do not seem to be able to prioritize selection for old over new elements.

More recently, Atchley, Jones, and Hoffman (2003) also reported results indicating that prioritized selection of new over old elements is based on a bottom-up process. They too found that if observers search for a target that appears with equal probability among the old and new elements, observers prioritized selection of new over old elements. In their Experiment 1, observers searched for a target letter "H" among distractor letters "A". In one condition, the target was presented with equal probability among the old elements (through the offset of the top-line segment of an old distractor "A" upon the appearance of the new elements) and among the new elements. The results showed that search efficiency was always higher if the target occurred among the new elements compared to if it occurred among the old elements. These results are consistent with the idea that the preview benefit is due to the operation of a bottom-up process.[3]

Recently, Donk and Verburg (2004) provided further evidence favouring the onset account. They allowed observers only a very brief preview of the old elements (i.e., 50 ms). They used the preview paradigm in which the number of old and new elements were independently manipulated. Observers searched for a target that could only occur among the new elements. In one condition, old elements were presented equiluminant with the background followed after 50 ms by the addition of the new elements. New elements were presented with luminance onset. Upon presentation, the luminance of the new elements was higher than that of the background. After another 50 ms the luminance of the new elements was set off to the luminance level of the

[2] In Experiment 4, Jiang et al. (2002b) had participants to indicate whether the rotation of a target "T" was up, down, left, or right. The target was always presented among the old elements containing multiple L-shaped objects. New elements consisting of multiple rotated "T"s were added to the display after 150 ms. The results indicated that participants were able to correctly report the identity of the target in about 65% of the trials. Jiang et al. inferred on the basis of these results that observers can prioritize the selection of old over new elements. However, it should be noted that if prioritized selection for old elements had been perfect, performance should have been close to 100%.

[3] It is important to note that the results of several other studies (Humphreys, Watson, & Jolicoeur, 2002; Olivers & Humphreys, 2002; Watson & Humphreys, 1997, 2000) suggest that prioritized selection is based on top-down processing. These studies have, however, generally utilized a preview task in which old and new elements not only differed in their temporal onset, but also in colour. If there is, however, no colour difference, as in Atchley et al. (2003) and Donk and Theeuwes (2003), prioritized selection seems to be completely bottom-up driven.

background and that of the old elements. In the other condition, both old and new elements appeared with an initial higher luminance. The results indicated that participants were able to prioritize selection of new over old elements when new elements were presented with luminance onset whereas old elements were not. New elements could not be prioritized if both old and new elements appeared with luminance onset. Donk and Verburg concluded that new elements can be prioritized over old elements, even with a very brief preview. However, if the presentation of the old elements is accompanied by luminance onset, attention might be captured by these onsets (Theeuwes, 1991; Yantis & Jonides, 1990). It might take a certain amount of time before attention can be completely disengaged from the locations of the old elements (Duncan, Ward, & Shapiro, 1994). As a consequence, during this interval new elements may fail to capture attention. The results of Donk and Verburg provided evidence for the onset account: Prioritization of new elements seems to be based on an instantaneous process rather than on a time-consuming process. If prioritized selection would have been caused by inhibition or segregation, prioritization should not have occurred in the present experiment. Both, the inhibition accounts and the temporal segregation account assume that observers need time to prioritize selection of new elements.[4] Recently, Belopolsky et al. (2005) demonstrated that, even without a preview interval, elements that appear with luminance onset can be perfectly prioritized over elements that appear without luminance onset. These results suggest again that the mechanism responsible for prioritized selection is not based on a time-consuming process of inhibition. Furthermore, these results demonstrate that a temporal separation between two groups of elements is not crucial for prioritized selection. These findings argue therefore against both inhibition accounts as well as the temporal segregation account.

Together the above findings provide evidence for the view that if old and new elements cannot be discriminated on the basis of a simple feature, the preview benefit appears to be caused by onset capture (Donk & Theeuwes, 2001). According to this account, new elements receive attentional priority in a purely stimulus-driven manner. It seems as if the abrupt onsets accompanying the appearance of the new elements generate a large bottom-up activation biasing observers to prioritize the processing of new elements over old ones. At this point it is important to note that even though the above results cannot be explained by visual marking, feature-based inhibition, or the temporal segregation hypothesis, it is conceivable that

[4] Jiang et al. (2002b) remark that the interval between the presentation of the old and new elements should be "long enough for attention to be deployed to one group and not the other" (p. 719). They suggested that the required length of this interval should be at least 200 ms.

other mechanisms play an additional role. The extent to which this occurs is a question for further research.

CONCLUSIONS

The above sections aimed to provide an overview of research on how people prioritize the selection of new over old objects. The first section provided a review of studies using the preview paradigm of Watson and Humphreys (1997). The results of these studies demonstrated that if old and new elements differ in a simple feature value, people apply feature-based inhibition in prioritizing selection of new over old elements. It is important to note that the demonstration of feature-based inhibition in the preview paradigm does not imply that the preview benefit is necessarily *caused* by feature-based inhibition. In fact, the results discussed in that section (e.g., Braithwaite & Humphreys, 2003; Braithwaite et al., 2003; Olivers & Humphreys, 2002, 2003) are also compatible with the idea that prioritized selection is caused by another mechanism while observers apply colour-based inhibition to optimize selection of the relevant subgroup. Indeed, as outlined in the second section, if old and new elements share their basic features, the preview benefit does not seem to be caused by inhibition. The results presented in that section suggest that prioritization of new over old elements seems to be primarily caused by onset capture (Donk, 2005; Donk & Theeuwes, 2001, 2003; Donk & Verburg, 2004). It was shown that prioritized selection of new over old elements: (1) Depends on the luminance onset characteristics of the new elements, (2) is mediated by a bottom-up process, and (3) occurs instantaneously upon the presentation of the new elements. Together, the results presented in this second section provide evidence favouring the onset account. Nevertheless, other mechanisms, such as inhibition or temporal segregation, may play an additional role to optimize selection of the relevant subset of elements.

Recently, Donk (2005) had observers search for a target that was presented at variable intervals after the presentation of the new elements. Old and new elements could not be discriminated on the basis of a simple feature. The results demonstrated that the preview benefit decreased as the interval between the presentation of the new elements and the target increased. It is conceivable that, in order to prioritize selection of new over old elements, onset capture is effective during the first several hundred milliseconds after the presentation of the new elements. To optimize subset selective search afterwards, observers may use other mechanisms. The extent to which such another mechanism plays role may depend on the exact stimulus configuration and instructions. Currently, it remains to be seen how the alternative mechanisms put forward to account for the preview benefit

can work in concert. A major challenge for future research is to determine how these different mechanisms act in concert to achieve prioritized selection for new elements.

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